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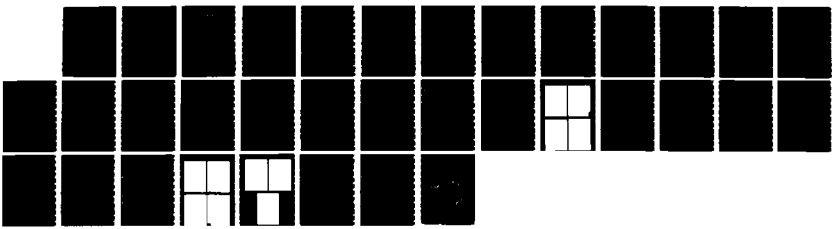

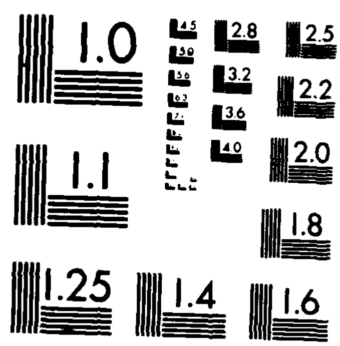
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THE MEASUREMENT OF DIPOLE ANGLE DISTRIBUTION AT TYPICAL AIRCRAFT ALTITUDES

FINAL TECHNICAL REPORT

by

JOHN H. WILKIN

JULY 1986

United States Army

EUROPEAN RESEARCH OFFICE OF THE U.S. ARMY

London England

Contract No. DAJA45-82-C-0003

Contractor - CRYPTEC

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of the cloud of dipoles and the angle of flight of the individual dipoles. The whole experiment was conducted by remote control from outside of the altitude chamber. Measurements were also made under sea level conditions for comparison with earlier experiments. The final results were that the flight angle characteristics at high altitude were virtually identical to those at sea level.

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Measurements were made of the distribution of the flight angle of aluminised glass chaff dipoles at a simulated altitude of 10 km and a temperature of minus 20 degrees Centigrade. The method employed was to dispense the dipoles in an airstream flowing vertically upwards, photograph the dipoles and analyse the film. The vertical airstream was obtained from a vertical wind tunnel and the experiment placed a complete wind tunnel with all of the support and measurements facilities of lighting system, dipole dispenser, and cameras into a high altitude chamber and recorded the dispersion of the dipoles, the growth of the cloud of dipoles and the angle of flight of the individual dipoles. The whole experiment was conducted by remote control from outside of the altitude chamber. Measurements were also made under sea level conditions for comparison with earlier experiments. The final results were that the flight angle characteristics at high altitude were virtually identical to those at sea level.

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CONTENTS

THE MEASUREMENT OF DIPOLE ANGLE DISTRIBUTION

AT TYPICAL AIRCRAFT ALTITUDES

INTRODUCTION

Background

A study was undertaken for the European Research Office of the U.S. Army in 1982 to measure the angle at which aluminised glass chaff dipoles fly. The final report was entitled "The measurement of Dipole Angle Distribution", Contract Number DAJA-81-C-0182.

The results of the research showed that for the first 5 or 10 seconds after the dipoles are dispensed into the air they are distributed across all angles between the horizontal and vertical. However, from then on by far the greater proportion of the dipoles fly at angles very close to the horizontal. Even when dipoles are dropped so that they are initially vertical they quickly revert to a horizontal orientation. At no time did horizontal dipoles change to a vertical or any other orientation.

These results were obtained with typical operational chaff and the measurements were made under sea-level conditions. Check measurements, an extensive experience off dipole flight characteristics and sea level dual polarisation radar measurements give a high level of confidence that the results were true and representative for the conditions of the tests.

However, there have been radar measurements made of chaff clouds at typical aircraft altitudes which have indicated that the predominant flight motion, in those tests, was vertical or at least greater than 45 degrees to the horizontal. It is possible to speculate at length on reasons for the differences between the two sets of conditions, relevant factors are that the two sets of measurements were performed at different altitudes of course but also, in the laboratory experiment, there was no significance turbulence in the air stream, no bidnesting (massive tangling of the dipoles) and only very high quality chaff was used. There is one particular manufacturing fault in chaff which causes the radar response in vertical polarisation to be greater than that in horizontal polarisation or, in other words, the predominant flight angle to be greater than 45 degrees to the horizontal.

The laboratory research was conducted to provide baseline measurements for future reference and this it did very well by simulating sea-level zero turbulence conditions. Using these baseline measurements the research is extended here to measure the angles at which dipoles fly at typical aircraft altitudes but still within the controlled conditions of a laboratory measurement.

This work is then an extension of a proven method and, just to make

sure, some of the original measurements were repeated for comparison. The work was concerned with the extension of the research only into the high altitude region because the investigation of the effects of turbulence would generate more work than could be accomodated within the cost constraints of one proposal.

The measurement of dipole flight angle is not easy by any means. Dipoles are very small and so the requirements placed on the recording system are quite severe. It is necessary to register on film hundreds of moving dipoles, each about 0.001 inch diameter, sufficiently clearly for the flight angle to be measured during the film analysis. However after a number of time consuming but rather mundane difficulties the measurement was finally accomplished.

OBJECTIVES

To launch an aluminised glass chaff cloud into the conditions of air pressure and temperature which prevail at an altitude of 10Km and to measure the angles at which chaff dipoles fly. Since the flight angle is not the same for all dipoles the distribution of the dipole angle was to be measured and since the flight angle is not constant, the time variation of the distribution was also to be measured over a period of 60 seconds.

METHOD

The approach used in this work was to track the centre of the chaff cloud with a camera while giving the cloud a velocity equal to, but opposite in direction to, its mean fall velocity. This approach was based on the principle that if a dipole, which has a fall velocity in still air of 0.3 m/s, is dropped into an airstream which is travelling vertically upwards also at 0.3 m/s, then the actual fall rate of the dipole will be zero. The dipole will appear fixed in space and its flight motion can be readily examined visually and therefore photographically. Similarly, if a cloud of dipoles is dropped into a smooth, controlled, vertical airstream where the air velocity has been carefully equalised across the width of the cloud then the growth of the cloud can be studied for tens of seconds.

The construction which produces the vertical air stream is traditionally referred to as a vertical wind tunnel. The experiment placed a complete wind tunnel with all of its support and measurement facilities of lighting system, dipole dispenser, camera and control systems into a high altitude chamber and recorded the dispersion of the dipoles, the growth of the cloud and the angle of the individual dipoles at the low pressure and temperature typical of an altitude of 10Km.

The film was projected on to a screen and analysed one frame at a time. The angle of each individual dipole on the frame was measured and graphs of dipole number versus flight angle were plotted to provide the distribution of the flight angle of the dipoles. Additional graphs were plotted at varying time intervals after the launch of the dipoles to illustrate how the flight angle distribution changed with time.

Description of the wind tunnel

The vertical wind tunnel is essentially a vertical, square section duct with a variable speed motor and fan combination installed at the bottom end. The fan draws air in from floor level and sends it vertically up the duct where it escapes at the top from the open end of the duct. The cross section of the duct is 1.15m (46in.) square and the height was 2.1m (7ft) before the work started. Three of the walls of the working section, that is, that part of the duct where the chaff is dispersed and photographed, are made of glass and the fourth side is painted matt black for use as a photographic background. The height of the working section is 1.4m (55in).

The tunnel uses a single fan driven by a variable speed DC motor with a thyristor controller. This combination gives a fan speed range of 100:1. The motor and fan are incorporated into the base of the tunnel to give a very compact piece of equipment.

No attempt has been made to use a streamline flowpath or to use flow director plates. On the contrary, a diffuser baffle assembly is incorporated directly into the fan exhaust to force the airflow perpendicularly towards the sides of the tunnel. This ensures that the cross sectional area of the airflow is immediately increased from that of the small fan aperture to that of the large area of the working section. In addition, the diffusing baffle method is less affected by fan speed variations than if flow director plates are fitted, which dramatically change the velocity profile when the fan speed is varied.

Inevitably, turbulence increases around the fan exhaust using a diffusing baffle process, but this problem is overcome by two further diffuser stages which are incorporated downstream of the fan and diffusing baffle combination. These additional diffusers are designed to provide a resistance to the airflow. The increase in pressure on the fan side of the diffuser tends to reduce lateral pressure differences on the diffuser (that is, perpendicular to the airstream) and so helps to reduce velocity variations within the working section.

The air velocity in the tunnel is very low, at only 0.3m/s for aluminised glass under sea level conditions, which is about one third of normal walking pace. Indeed, it is so gentle that when reaching into the tunnel to retrieve a dipole, the flow of air cannot be felt on the hand or face.

The tunnel (and recording system) is the same as was used for the original sea level measurement of dipole angle distribution but was modified so as to fit into, and be used with, the high altitude chamber, as described below.

The High Altitude Chamber

The chamber is installed at The Institute of Aviation Medecine at Farnborough in the United Kingdom and is normally used for measurements

on aircrew and their equipment for the British Royal Air Force. The chamber can simulate conditions well beyond the altitude and temperatures used in these measurements, so effectively the chamber was transparent to the experiment.

The altitude chamber was physically very large overall but the volume available for experimental use was rather small at 2.7 metres diameter by 4.3 metres long. The available headroom was only 2.3 metres because an open mesh metal grating floor was installed across the bottom of the chamber.

At the time of the experimental work the altitude chamber could not meet the national standards for maximum permitted time to return to ambient conditions in an emergency therefore the experiment had to be done by remote control from outside of the chamber. A complete control system was assembled to do this as described below whereas the original sea level measurements were made using available instrumentation and several operators to control it.

The Measuring System

The system was composed of six main parts; the cameras, the film, lenses, lights, screens and the background against which the dipoles were filmed.

Two cameras were used to record the dipole flight, a 35mm cine camera running at normal cine camera speed and a still camera, also using 35mm film although the frame size is very different between the two cameras of course. The two cameras were positioned side by side and firmly bolted to the same heavy mount but they had different fields of view and different times for which the shutters were open.

The reason the still camera was added to the system for these measurements was that it should provide a better resolution since the film would be more stable during each exposure, the film would be easier to analyse and the measurements should be more accurate. There was a subsidiary reason that there is a greater choice in zoom lenses available for still cameras and so it was easier to fill the frame with useful information.

The cameras were permanently mounted on a heavy very stable tripod throughout the measurements and this was installed on a 'spreader', a device to prevent the tripod feet moving. Neither the wind tunnel nor the tripod were moved during the whole time the equipment was in the altitude chamber.

The direction of view of the cameras was in the horizontal plane and perpendicular to the glass front of the wind tunnel. It was arranged that the cine camera and the centre of the dipole cloud, when it was formed, were in the same horizontal plane. The cameras did not need a screen between them and the glass because the camera had been shielded from all light sources and there were no significant reflections of light from the glass visible within the field of view.

The film which was shot at each stage was immediately developed and viewed while the experimental equipment was still set up. This enabled repeat runs to be made very quickly if faults were discovered in the film.

The cine camera ran at twenty four pictures per second throughout the work. It could easily run at higher speeds than that simply by changing the setting on the camera motor but there was no reason to do so.

There was no need to use high speed film since the level of illumination was not a major problem and the dipole motion within the frame was quite slow. But definition was all important and so a low speed, high definition film was used in the cine camera. Kodak Plus X 5231, black and white filmstock was employed throughout this work; it was rated at 64 ASA (tungsten). The still camera was loaded with Ilford HP5 film rated at 400 ASA which is somewhat faster. This choice was made to help with experiments on varying shutter speed as described below.

Black and white film was used in both cameras as this gave the highest contrast and best resolution. There was no advantage in using colour film because the subject was a cloud of 'white' dipoles against a black background.

The lighting system used four quartz halogen units operating at a colour temperature of 3400 degrees Kelvin. Two of these were positioned on either side of the tunnel, a 2kW one at the front and an 800 watt one at the back. A screen was positioned between the two lights on each side of the tunnel. Two more screens, again one on each side of the tunnel, were used to shield the cameras from the lights.

The internal surface of the high altitude chamber was coated with a special material of pastel pink colour necessary for other applications of the chamber. The coating reflected a lot of light back into the shadows but the final contrast achieved on the films was quite good.

Operational aluminised glass chaff was used for all of the measurements, it was carefully cut to dipole length and checked for quality before use with particular attention being given to dipole separation and dispersion. The chaff used for the graphs below was manufactured by Lundy. Tests were made with Tracor chaff for comparison but there was no apparent difference. 28mm dipoles were used throughout all of the measurements reported here.

The dispenser employed to launch the dipoles into the wind tunnel is a proprietory unit developed by Cryptec over a period of years to do this particular job. It is able to dispense a stream of dipoles by remote control with infinite resolution of the rate at which dipoles are released, this is necessary to control the amount of birdnesting. It can dispense the normally used range of dipole lengths over a fraction of a second or continuously over minutes or even hours and unnattended if necessary. It can be set to dispense the dipoles so that they have an initial flight angle at any angle between the vertical and the horizontal. Dipoles were launched so that they were initially vertical in these experiments.

The Control System

The altitude chamber was a completely sealed environment so modifications had to be made to the existing wind tunnel system to make it fully remote controlled so that it could be operated successfully without direct sight of what was happening in the tunnel.

Prior to this series of measurements the system had been electrically controlled from the cine camera position using two operators to synchronize dipole dispensing into the tunnel with camera operation. The change to remote control using a video system for feedback was combined with modifications to have everything operated by one person.

Almost all of the original separate controllers were rebuilt and installed into one 19 inch rack unit which finally contained eight thyristor controllers. There was one for each of the four lights, the dispenser and the motor which powered the tunnel fan, each of which gave infinite control between 0 and 100% of full power. In addition the cine camera had its power supply installed within the 19 in rack with a simple on-off controller (the frame rate was set on the camera itself) and an on-off controller for the still camera which when turned on released the shutter to make the exposure and when turned off advanced the film and reset the shutter mechanism ready for the next photograph.

Time was measured and recorded by an electronic digital timer included within the frame of the film throughout the experiments. The timer was crystal controlled, not that high accuracy was required since the display was only in seconds and tenths of seconds. The timer was in the 19 in rack unit outside of the altitude chamber with one display for the operator but there was a second display inside the chamber for the cameras, both were driven from the same counter. The one inside the chamber was positioned just in front of the glass wall of the wind tunnel and within the field of view of both cameras. The last of the eight controllers, referred to above, performed the interfacing to the timer and the multiplexing and line driving for the remote display installed inside the altitude chamber.

The front panel of the 19 in rack was very simple. There was a knob to control the setting of each of the four lights, another knob for the setting of the wind tunnel motor and one for the settting of the dipole dispenser. During a measurement run the lights were turned up to maximum and the wind tunnel was preset to the balancing air velocity, so all of those controls could then be ignored. The dispenser control was operated to form a cloud in the tunnel and then turned off. There were then just two switches left for the operator to use, one was the reset switch which was used only at the very end of a run and the other was the camera switch.

The reset and inhibit controls for the timer were electronically interlocked with the camera switch so that when the reset switch was pressed the timer was set to zero and held there. When the camera switch was pressed the cine camera started and and the still camera exposed one frame. When the camera switch was released the cine camera stopped and the still camera motor drive advanced the film to the next

frame and reset the shutter but the timer was not stopped. Subsequent operations of the camera switch repeated this intermittant operation of the cine camera and operation/resetting of the still camera without affecting the timer. The timer ran until the next operation of the reset switch at the end of the filming sequence. So the intermittant movie camera operation plus still camera operation without resetting the timer was possible by one operator using just one switch.

The video system was already installed in the high altitude chamber as part of its normal instrumentation. The video camera was on a fixed mount bolted to the floor and completely separate from the wind tunnel instrumentation. Additional screens were positioned around the camera to reduce glare from light reflected from the roof of the chamber and thereby improve contrast. There was a fault on the camera such that it operated only at maximum contrast. It wasn't possible to repair the fault in time for the experiment but it probably did not matter since the subject was at maximum contrast anyhow.

The glass wall of the tunnel through which the cameras viewed the dipole clouds had data written on it so that it appeared on the films. There was a horizontal line (put on with a spirit level) which was used in the analysis as the reference against which to measure the dipole angle. The dipole length and run description, which served as a film sequence identifier, was also included and these can be read from the stills reproduced below. When the altitude chamber was sealed between runs the film sequence identifier covered all of the runs involved and so at first sight did not seem completely sensible.

THE DEVELOPMENT OF THE RECORDING SYSTEM

Modifications

A number of modifications were made to the wind tunnel system specifically to tailor it to fit into the high altitude chamber so that these measurements could be made. The modifications were needed because there was a relatively small space available for experimental purposes in the altitude chamber, compared with the size of the wind tunnel. Although the overall size of the chamber was very large most of it was taken up with support machinery.

The rather small diameter of the experimental volume meant that the overall height of the tunnel had to be reduced just to get it into the chamber. This was done in three ways, first by repositioning the lights to the side of the tunnel instead of immediately above the duct where they had been during the original sea level work. Secondly by removing one diffuser from the tunnel itself and thirdly by mounting the dispenser directly on the top of the wind tunnel duct whereas it had been nearly a metre above the top of the duct. The loss of this metre meant that it was not possible to look at dipole flight interaction in the clouds because there was not enough space availabe for the dipoles to stabilize after dispensing and then allow room for the vertical growth of the cloud above the diffuser. Correspondingly no attempt was made to record the first five seconds of cloud life as was done in the original sea level work.

The repositioning of the lighting units caused a set of problems. The lights were normally at a considerable distance from the working section of the tunnel. There wasn't enough space to do that this time, so a framework of outriggers was built from the main frame of the tunnel at the level of the diffuser and the lights were mounted on the outriggers.

Setting Up

A sequence of experimental tests were made on each part of the system to develop the method so as to reach the best possible standard of definition on the film.

The first things that had to be done after installing the system into the altitude chamber was to measure the uniformity of the airflow across the tunnel, tailor the lighting system and the screens to get the best image contrast, improve the video picture and then prove that everything worked correctly ready for the final measurements.

The variation in velocity across the dipole cloud was important and considerable care was taken throughout the setting up phase of this work to achieve as small a variation as possible

The typical fall rate of an aluminised glass cloud is 0.3 metres per second and with the airflow set to give that speed in the centre of the tunnel then the maximum variation anywhere in the tunnel was 0.01 metres per second about that level by adjusting some of the diffusers and replacing others with alternative materials.

The air velocity measurements were made with a hot wire anemometer calibrated for use in the range 0 to 2 metres per second. Measurements in this region are notoriously difficult and high accuracy was not needed so a commercially available laboratory instrument was used.

It was not feasible to measure the air velocity in the tunnel at high altitude but it was evident that there was no major variation in the velocity differential across the cloud just by observing how the dipoles flew under those conditions.

There were a number of viewing ports in the chamber which were fitted with telescopes. So it was possible to physically see a real cloud to assess the uniformity of the air flow but it was not feasible to use them for the filmed measurements which had to be made using the video system.

It seems as if it was a very simple process when reporting that the positions of the lights and the screens were adjusted to get the best possible contrast between the dipoles and the background on the film. But the effects of the lights together with the screens and the reflecting surfaces around them in such a small volume were strongly interrellated and so the amount of effort involved was out of all proportion. It took a long time.

Exposure tests were made by varying the aperture of the lens using the

best lighting conditions from the previous experiments. The base line was obtained by taking the exposure meter reading of a matt finish aluminium sheet inclined relative to the lights and the direction of view of the camera so that there was no direct reflection into the lens. Finally several photographic sequences were shot of 16mm and 28mm dipoles in separate clouds to assess the results of the development of the overall recording system.

Several experiments were undertaken in varying the shutter speed of the still camera. The fastest shutter used was equivalent to 1 millisecond duration but while the definition of what could be seen was very good, it was rather difficult to be sure what was a dipole and what wasn't. So the shutter speed was progressively reduced until the final duration of 12ms seemed to give the best overall compromise and this was the value used for the final measurements. The slower shutter speed spreads the image out and makes the angle easier to measure.

There were also a number of experiments on varying the dipole length. The natural desire to increase the number of dipoles in each frame of the film really meant trying to use a 16mm dipole length. However dipoles as short as that couldn't be seen on the video display clearly enough to be sure of what was happening in the cloud, although they could be clearly seen on film. Since the final measurements had to be made with the video system as the only feedback from the altitude chamber the dipole length had to be increased. A length of 28mm was about the minimum which satisfied the video requirement and since it also gave a better image on film, and therefore more accurate angle measurements, that length was used for the rest of the work.

THE FINAL MEASUREMENTS

The wind tunnel wa made ready for the measurements by a series of actions before each film sequence was shot. These were the cleaning of the diffuser free of all chaff, cleaning the glass walls free of dipoles and remarking the run identifier on the front glass wall.

The lighting system was then checked and the position of the screens and their corresponding shadows confirmed by viewing through the camera viewfinder.

The cameras were checked for aperture setting, field of view and frame count before each run. The point of focus was confirmed by suspending a lens test chart, with full illumination, in the centre of the tunnel and the lenses focussed on it. Neither the cameras nor the lenses were touched after that. It was not necessary to touch the cameras even in multi-shot sequences because they were electrically operated and remotely controlled.

A detailed log was maintained of each shot taken by the still camera so it was clear when the cameras needed reloading with film and the shooting sequences were arranged within those boundaries.

The actual experiment started with the lights being brought up to full power from their reduced power standby mode, the dispenser was started

and the resulting cloud of dipoles checked for suitability for filming, that is there were no large birdnests of tangled dipoles in the cloud. This only took about one second.

The camera switch which started the timer, the cine camera and took the first still photograph was depressed to start the recording sequence. From that point onwards it was necessary to watch both the timer and the video display to be ready to make small adjustments to the air velocity in the tunnel to keep the cloud within the field of view or to abort the run if necessary.

The camera switch was then depressed at 5, 10, 20, 40, and 60 seconds to make the exposures for the rest of the recording sequence.

After the sequence was completed the timer was reset, the log brought up to date and the preparations made for the next run.

No attempt was made in these measurements to investigate the 0 to 5 second region of the cloud lifetime as was done during the sea level experiments. The reasons were the low dispenser position and the difficulties being experienced in achieving the primary purpose of the work of finding out whether the longer term flight angle was other than horizontal. This meant that the control switch was depressed for only one second or so and not continuously for the first five seconds as was the case during the original sea level experiments.

There were two primary measurement sequences, the first repeated the sea level measurements to confirm that there was no significant change from the original conditions and the second made the measurements under high altitude and low temperature conditions.

The experiment to duplicate the sea level measurements was performed with the wind tunnel in place in the altitude chamber with the chamber door open and before any low temperature work had been attempted. So the conditions were truly ambient temperature (ie + 20 degrees C) and sea level pressure. The only difference from the original sea level measurement was that the experiment was controlled outside the chamber using the video system for feedback.

The first attempts at the high altitude measurement were made with the wind tunnel airstream supporting the dipoles when the pressure in the chamber was equivalent to 10 km altitude but at laboratory ambient temperature.

The reason this was done was that a short time of fifteen minutes or so was needed to get to an altitude of 10 km (and a similar time to get back down again), but a long expensive time of 24 hours was needed to cool the chamber to minus 40 degrees Centigrade. The intermediate conditions were used to gain experience at altitude at minimum cost and risk and to see if there was much change in flight angle caused just by the different air pressure.

The altitude work had been approached with some trepidation since the new balancing air velocity in the wind tunnel might have been beyond the range of the system. There were also prospects of arcing in the

electical components which operated at 240 volts, 50 Hz and there were doubts as to whether the bulbs in the photographic lighting units would withstand the reduced pressure when they were hot.

Problems were experienced at low temperature as described below but there were no difficulties with high altitude alone. There was a much smaller change in fall rate of the dipoles than expected but the new fall rate was well within the range of the wind tunnel's motor/fan/controller combination.

Having successfully obtained good photographic images which showed the flight angle under those conditions the next step was to attempt an altitude of 10 km and minus 40 degrees Centigrade. But having carefully set the experiment up and waited for the chamber to go cold there were immediate major problems, all of which were related to the low temperature. Although low temperature greases were used in all rotating bearings, the motor/fan combination which gave the vertical airstream in the wind tunnel would not rotate and neither would the cine camera operate. The lights functioned without problems and there was no evidence of arcing. However, it was not realistic to persist with the attempt since as soon as the chamber was opened the glass misted removing any possibility of photography, so minus 40 degrees Centigrade was abandoned.

As the chamber was slowly warmed up in its return to room temperature the system was exercised periodically to find the temperature at which everything would function. This appeared to be around minus 20 degrees Centigrade so the decision was taken to attempt the measurement again at 10 km altitude and minus 20 degrees C. The return to room temperature was completed and everything was cleaned and reset after which the chamber was returned to that low temperature and pressure and the measurement successfully completed without further difficulty.

The altitude chamber was maintained at the low temperature by its own internal supply of cold air which was blown around the chamber at a significant velocity, probably 1 or 2 metres per second. The photographic screens around the tunnel were blown about in this wind to an unacceptable extent so the air velocity in the chamber was turned off during the measurement runs. This meant that the time available at low temperature was limited but there was no alternative. Removing the wind inside the altitude chamber also removed any worry that it might affect the airstream within the vertical wind tunnel.

There was an additional but secondary sequence, which was to take a number of photographs with the wind tunnel velocity at zero, that is the dipoles were falling in still air. This was done to demonstrate that the flight angle achieved was not being caused by the wind tunnel itself and also to provide comparison with a similar sequence in the original sea level measurements. For completeness photographs were taken with zero air velocity under all three conditions for which the angle distributions were measured.

After the film was processed it was projected as the negative, one frame at a time, on to white paper. The angle of each dipole was measured and its position marked on the paper so that it would not be recorded a

second time. The angles were recorded in a histogram table and then transcribed into graphical form for this report.

RESULTS

This section concentrates on the results of the film analysis which gave the distribution of the flight angles of the dipoles.

The detailed results are given in four series of graphs which show that the predominant flight angle is very close to the horizontal for all of the conditions investigated.

Some still photographs were taken from the original film. These are included here to put the measurements which follow into context, to show what the chaff clouds look like in the wind tunnel and to illustrate some of the features which influence the rest of the results.

Photographs are reproduced from the film of the zero velocity experiments where dipoles were dropped by the remote controlled dispenser into still air and photographed.

Dipole Angle Distributions

Sea Level and Ambient Temperature

The dipole angle distributions for the dipoles dispersed under sea level conditions are given in Figure 1. There are six graphs in the sequence and in each the number of dipoles recorded at each angle is plotted against the dipole angle in one degree increments between 0 and 90 degrees to the horizontal. The graphs correspond to the sequence of photographs within the range of 2 to 60 seconds following the launch of the dipoles into the wind tunnel.

All of the graphs have been plotted on the same scales to facilitate comparison between them and to reveal more clearly the pattern that unfolded. The format of the graphs is the same as was used in the original sea level measurements.

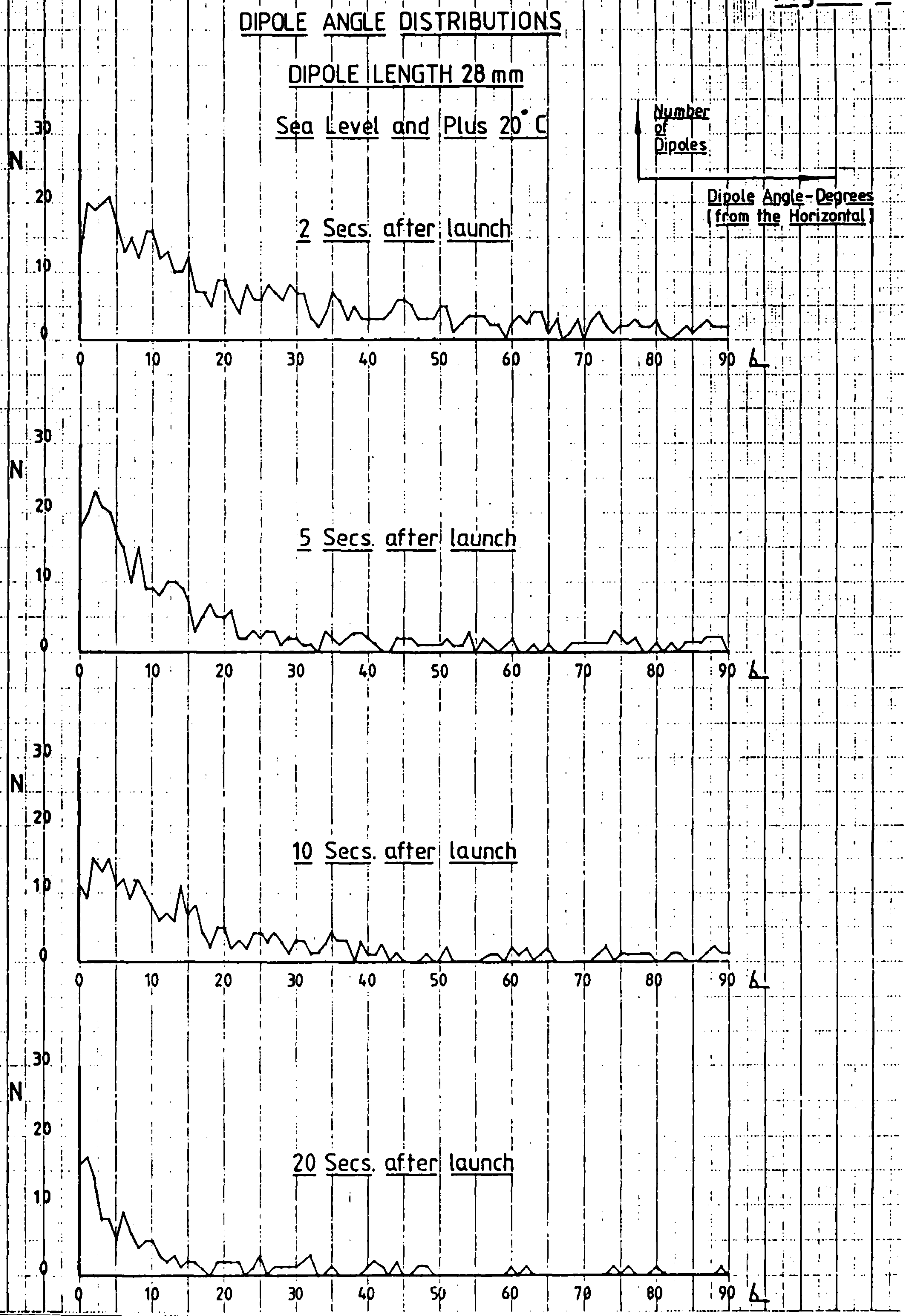
The graph for 2 seconds after launch shows that the dipoles were distributed over the full range from the horizontal to the vertical but that there was an apparent concentration between 0 and 20 degrees to the horizontal.

The graph at 5 seconds has a similar form to that at 2 seconds but the amplitude at all angles above 10 degrees to the horizontal has noticeably decreased.

The graph for 20 seconds follows the same pattern but the amplitude within the 0 to 10 degree region has also started to decrease.

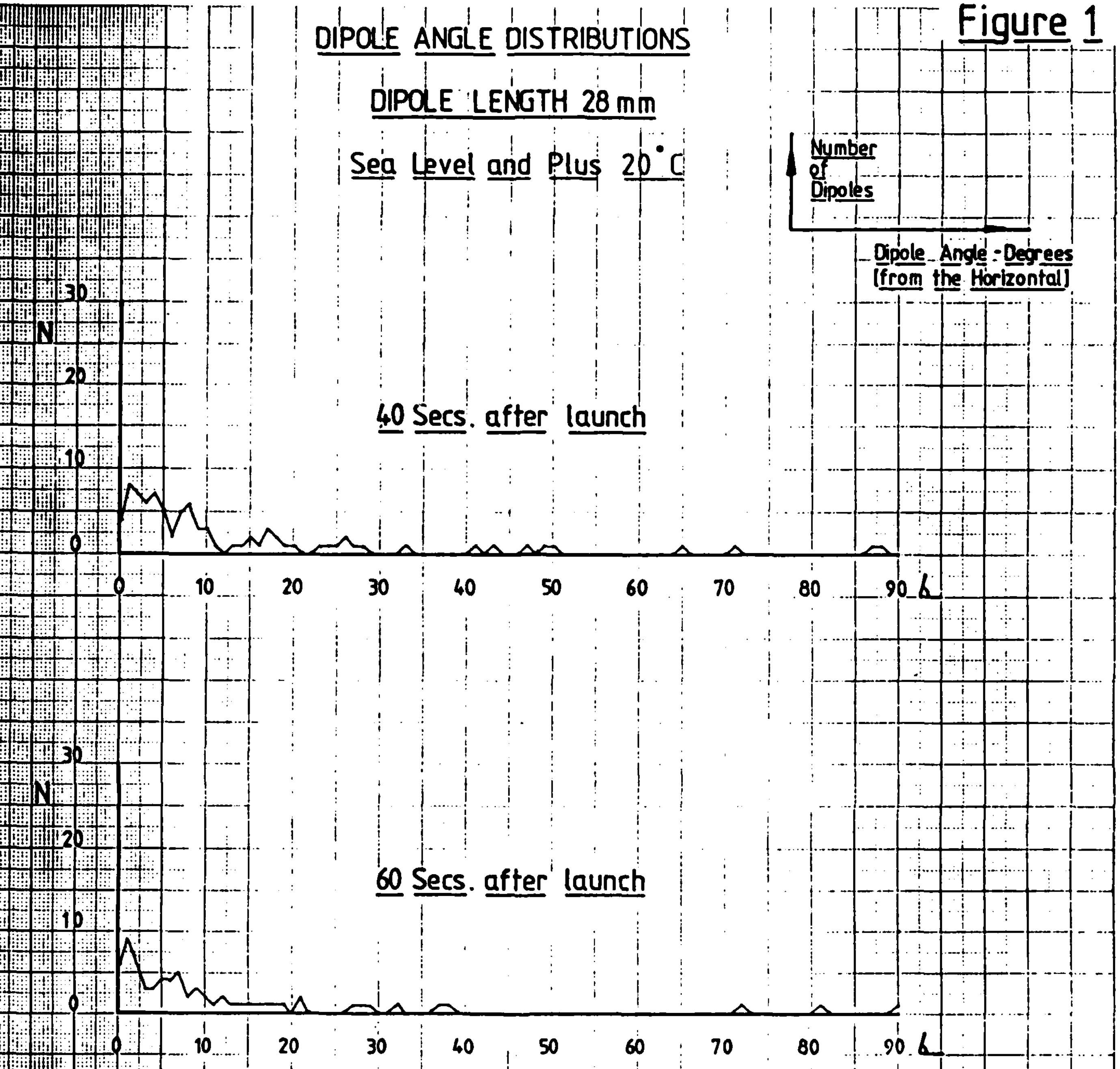
The rest of the distribution graphs at 40 and 60 seconds illustrate the decay in dipole numbers clearly by themselves and so do not need further comment.

Figure 1



DIPOLE ANGLE DISTRIBUTIONS
DIPOLE LENGTH 28 mm
Sea Level and Plus 20° C
Number of Dipoles
Dipole Angle-Degrees (from the Horizontal)
2 Secs. after launch
5 Secs. after launch
10 Secs. after launch
20 Secs. after launch
N
0
10
20
30
40
50
60
70
80
90

Figure 1


DIPOLE ANGLE DISTRIBUTIONS
DIPOLE LENGTH 28 mm
Sea Level and Plus 20°C
Number of Dipoles
Dipole Angle - Degrees (from the Horizontal)
N
30
20
10
0
40 Secs. after launch
0 10 20 30 40 50 60 70 80 90
N
30
20
10
0
60 Secs. after launch
0 10 20 30 40 50 60 70 80 90

A set of still photographs taken from the original film are reproduced in Figure 2. Only the first four photographs corresponding to the 2 second, 5 second, 10 second and 20 second measurement points are given since the others do not add any further information.

The horizontal line drawn on the glass as the reference against which the dipole angle was measured is readily apparent. The other glass markings refer to the dipole length of 28mm and the two runs which were made with these markings, that is, sea level conditions with an air velocity in the wind tunnel to balance the fall rate of the dipoles and also with the wind tunnel switched off (zero velocity). Multiple run markings were used because it was not possible to gain access to the inside of the chamber between runs.

The photographs illustrate how the greater proportion of the dipoles in each frame fly at angles close to the horizontal and how the proportion increases with time.

The set of angle distribution graphs which were produced during the original sea level measurements are reproduced here in Figure 3. The same general pattern of a concentration of dipoles close to the horizontal at 2 seconds with a subsequent rapid decay with time of the number of dipoles flying at high angles to the horizontal is again evident. So is the general decay in dipole number at the lower angles of flight. The results of the two separate experiments were sufficiently similar to accept comparability.

A notable difference between the two sets of angle distributions of Figure 1 and Figure 3 is that the increase in the number of dipoles near the horizontal at 5, 10 and 20 seconds is not reproduced in the more recent measurement. The most likely reason for this is a difference in the rate at which dipoles were dispensed into the airstream since the other factor which could produce the effect, the total number of dipoles dispensed in the two experiments, was similar. The earlier photographs show the rate was quite high because it produced a pronounced interaction between the dipoles effectively trapping them in the cloud. As the interaction subsided the dipoles returned to a near horizontal orientation before they had chance to change their position within the wind tunnel so they were still in the field of view of the cameras. The latest experiment does not show such a distinct interaction region which indicates a slower rate. The dispensing rate is operator determined and was not controlled between the two experiments since this characteristic, although indirectly known, had not appeared in measurement data before. The more uniform distribution in the 2 second graph of the earlier measurement supports this explanation.

10 km Altitude and Ambient Temperature

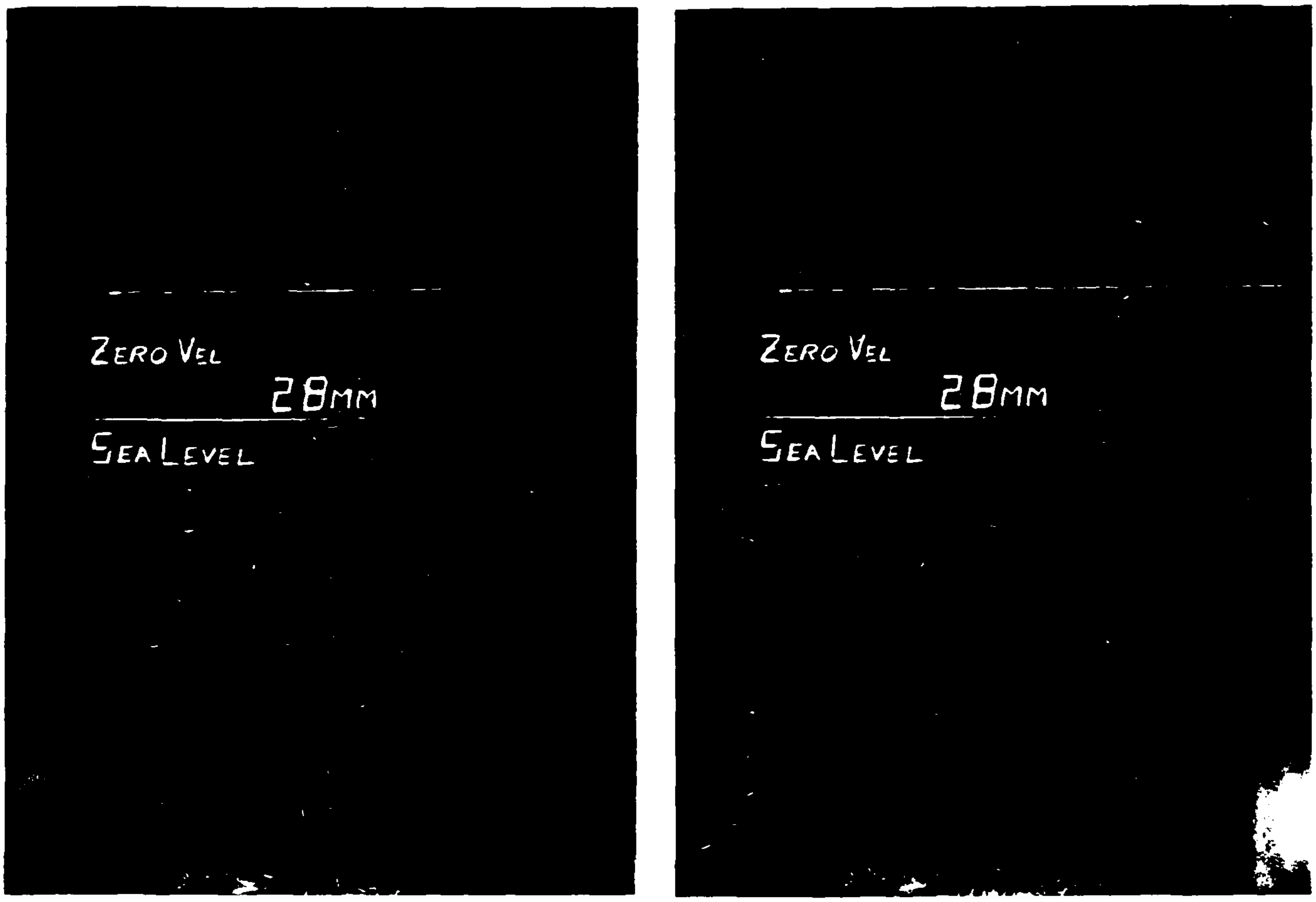
The angle distribution graphs for the conditions of 10 km altitude and ambient temperature of plus 20 degrees C are given in Figure 4.

They show a very similar pattern to that seen in the two sea level measurements above. A similar distribution at 2 seconds followed by the

CLOUD GROWTH IN THE WIND TUNNEL

Sea Level and Plus 20°C

Figure 2



2 secs. 5 secs.

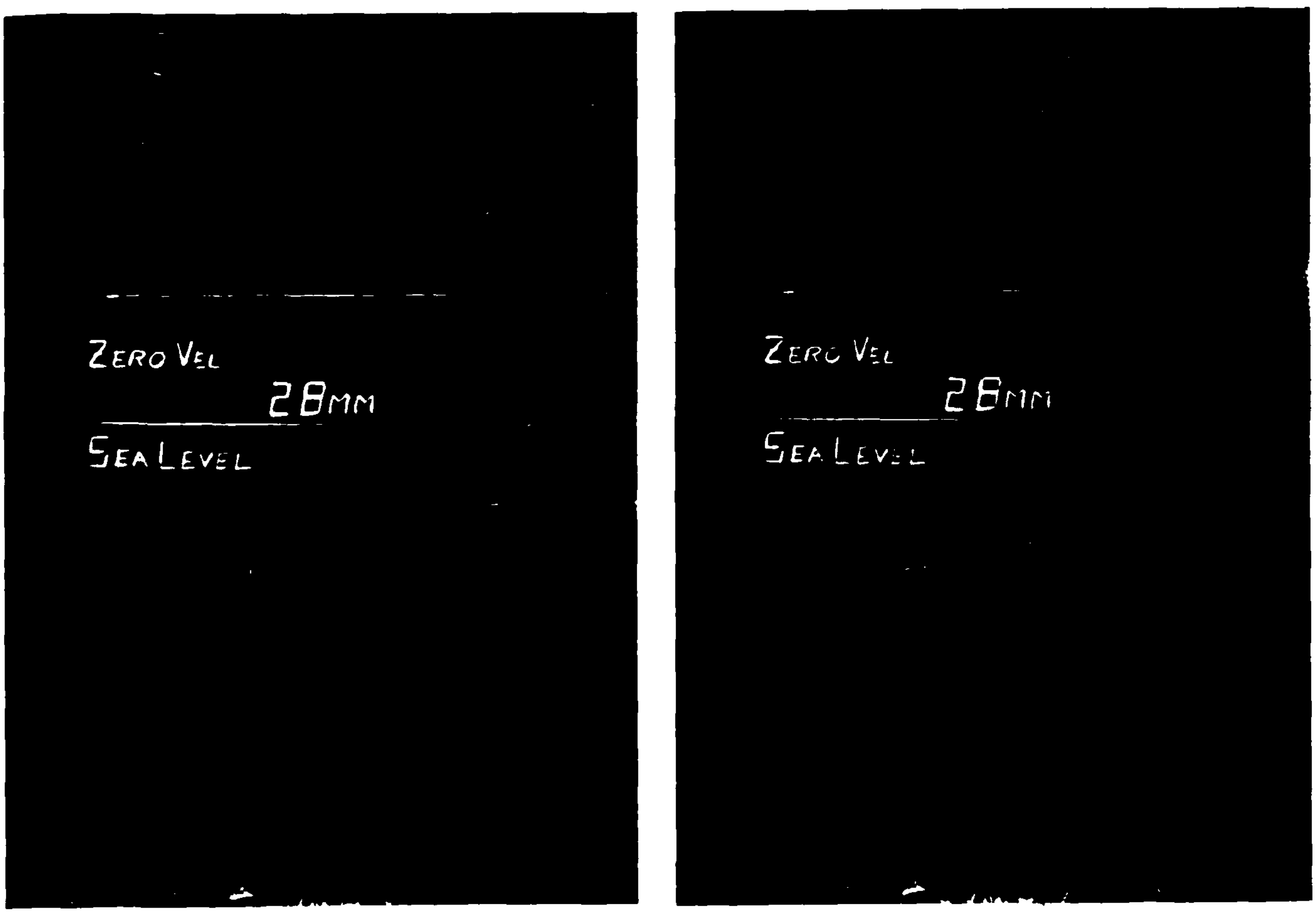
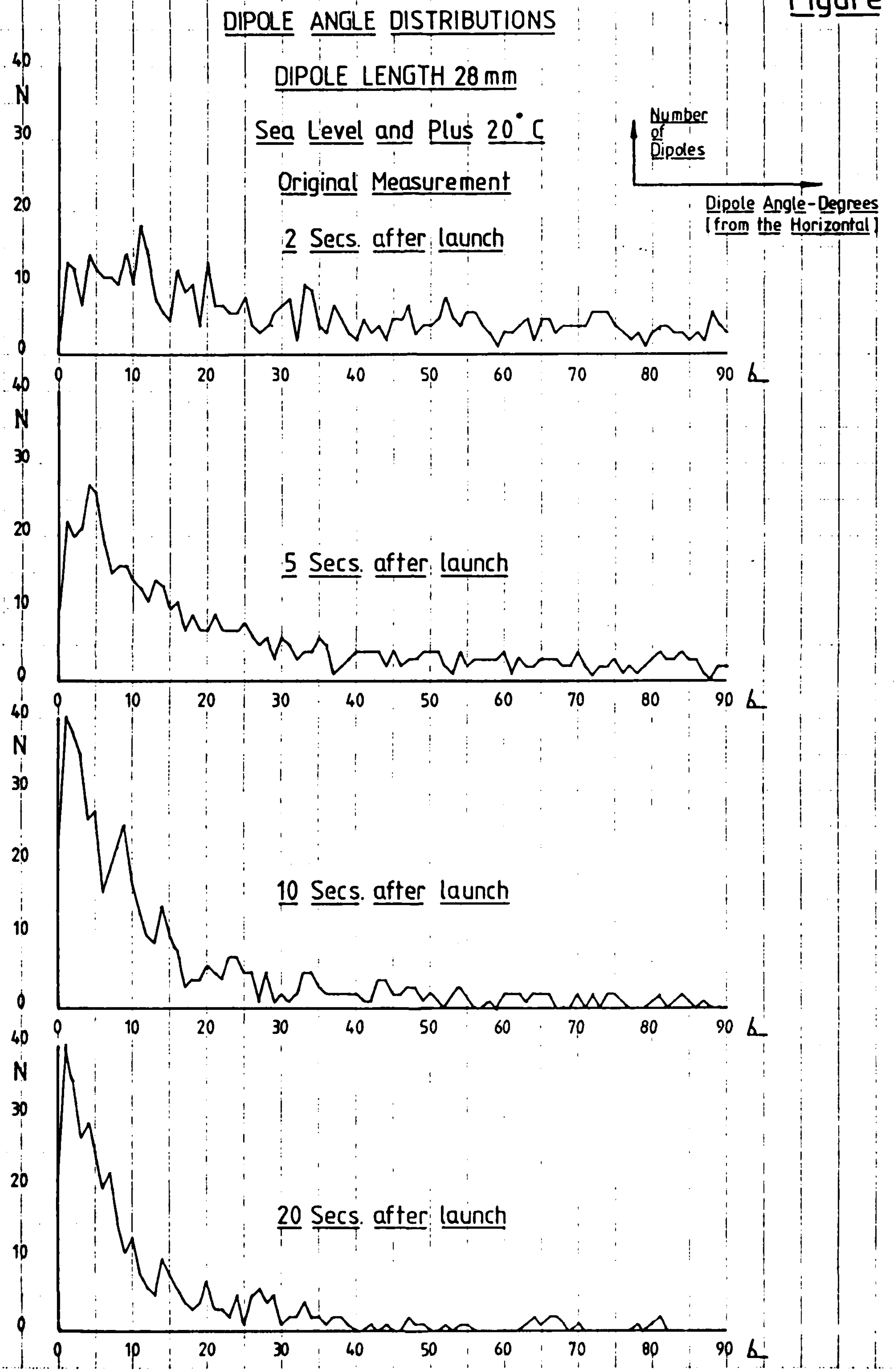
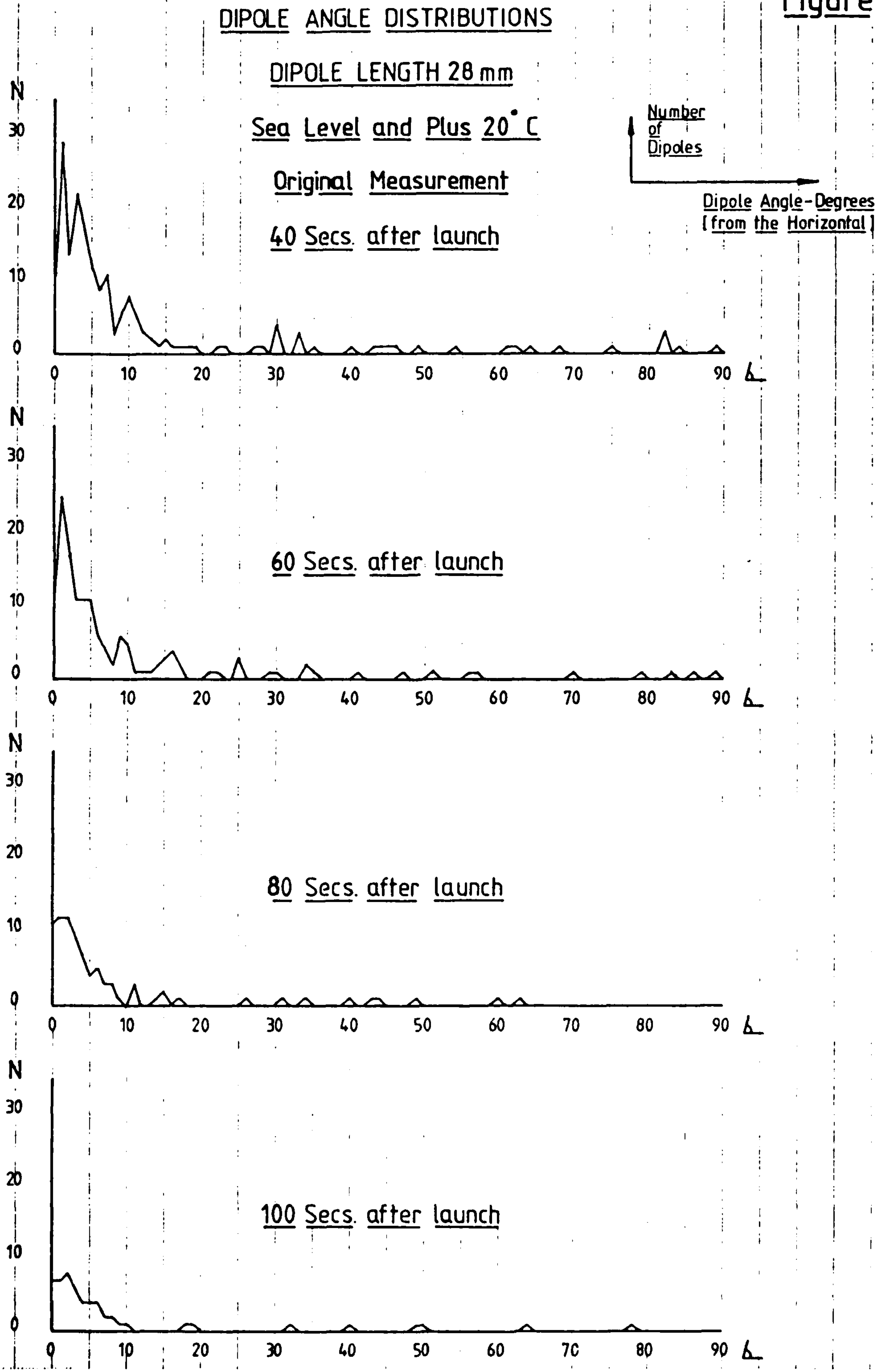


Figure 3



DIPOLE ANGLE DISTRIBUTIONS
DIPOLE LENGTH 28 mm
Sea Level and Plus 20° C
Original Measurement
Number of Dipoles
Dipole Angle - Degrees [from the Horizontal]
2 Secs. after launch
5 Secs. after launch
10 Secs. after launch
20 Secs. after launch
N
0
10
20
30
40
50
60
70
80
90

Figure 3



DIPOLE ANGLE DISTRIBUTIONS
DIPOLE LENGTH 28 mm
Sea Level and Plus 20° C
Original Measurement
Number of Dipoles
Dipole Angle-Degrees [from the Horizontal]
40 Secs. after launch
60 Secs. after launch
80 Secs. after launch
100 Secs. after launch
N
30
20
10
0
10
20
30
40
50
60
70
80
90

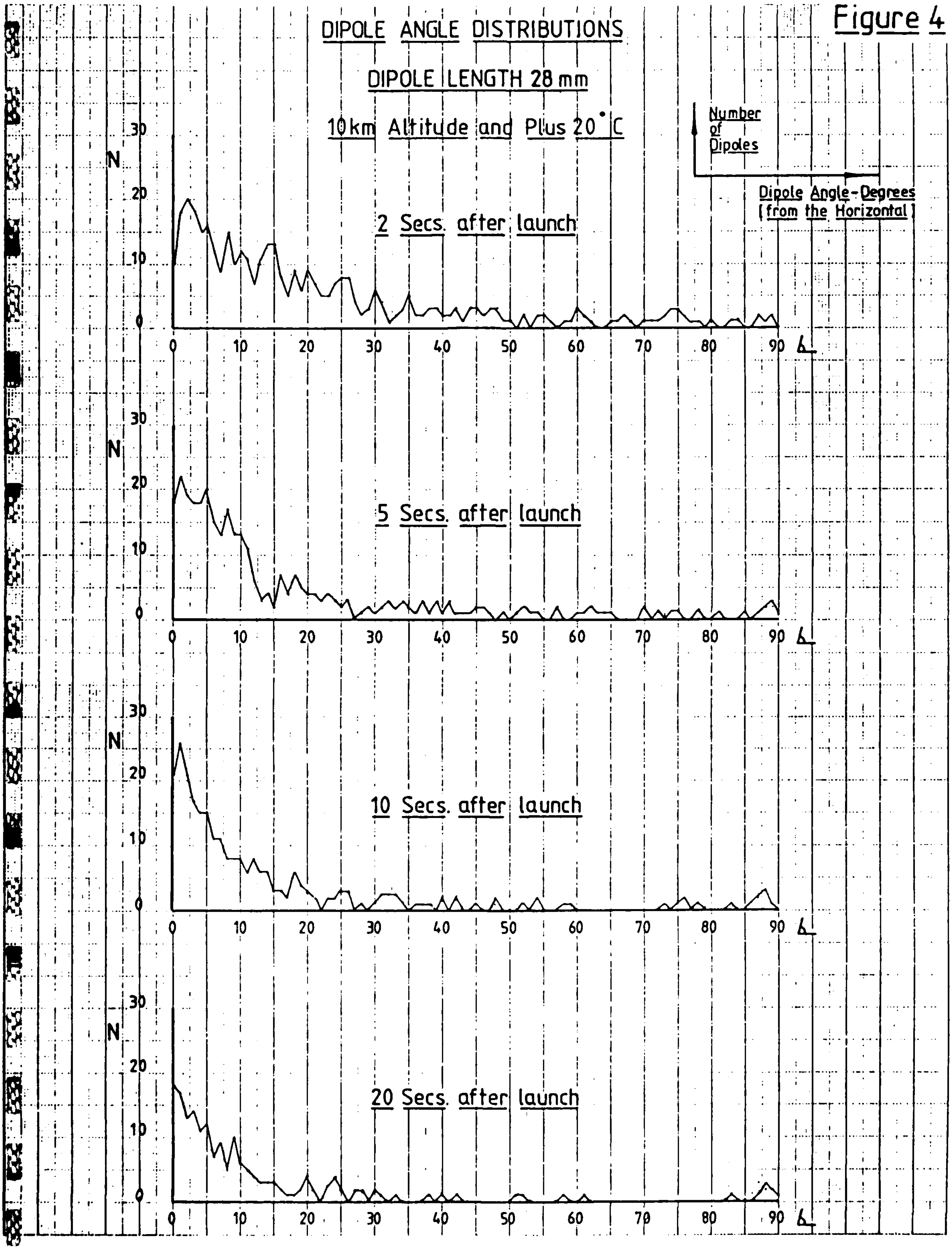


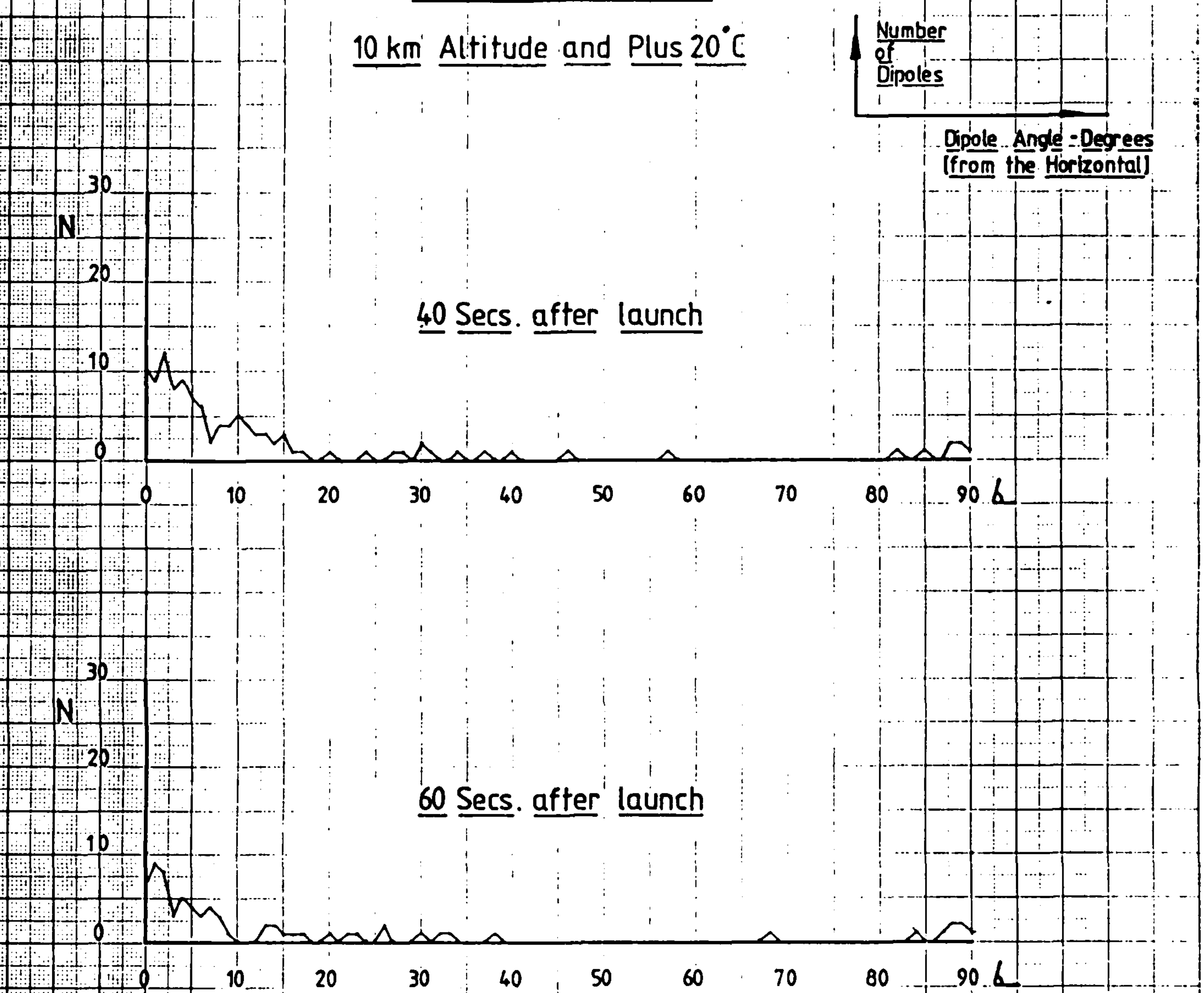
Figure 4
DIPOLE ANGLE DISTRIBUTIONS
DIPOLE LENGTH 28 mm
10 km Altitude and Plus 20°C
Number of Dipoles
Dipole Angle-Degrees (from the Horizontal)
N
30
20
10
0
2 Secs. after launch
5 Secs. after launch
10 Secs. after launch
20 Secs. after launch
0 10 20 30 40 50 60 70 80 90

Figure 4

DIPOLE ANGLE DISTRIBUTIONS

DIPOLE LENGTH 28 mm

10 km Altitude and Plus 20°C



same initial rapid decay and slower longer term decay are evident. There is perhaps a slight increase in the number of dipoles near horizontal at 5 and 10 seconds relative to that at 2 seconds but the increase is very small and really insignificant. Overall the change to high altitude seems to have had virtually no effect on the angle distribution, the greater proportion of the dipoles always fly close to the horizontal.

A few vertically orientated dipoles were stuck to the glass in the 10km ambient measurement. The same set appear in all of the graphs at around 90 degrees to the horizontal and can be tracked from graph to graph. They have an effect on the visual impression of the graphs which is disproportionate to the number of dipoles involved. They should be ignored.

10 km Altitude and Minus 20 Degrees Centigrade

The set of angle distribution graphs for high altitude and low temperature are given in Figure 5.

Yet again the same features of flight angle distribution are evident. The greater proportion of the dipoles still fly at angles close to the horizontal. The graphs indicate that the flight angle characteristics are independant of both altitude and temperature over the range of conditions considered in these measurements.

The number of dipoles at each angle in these and all of the other graphs is not sufficiently large to sensibly draw any conclusion from the granular peaks in the graphs. The accuracy of the analysis was better than plus or minus one degree but still the granular peaks have no significance.

Figure 6 presents a series of photographs of the cloud growth in the wind tunnel for the high altitude, low temperature conditions. The photographs illustrate the prevalence of the near horizontal orientation of the flight angle and the similarities with Figure 2 (sea level conditions) are readily apparent.

Some of the dipoles in Figure 6 are obviously not straight, they have a curvature. This is not a fault in the dipoles, it is typical. Chaff dipoles are usually assumed to be straight, in fact they never are.

ZERO VELOCITY EXPERIMENTS

Figure 7 consists of three stills taken from the original films, one for each of the three environmental conditions considered in this report. The one labelled sea level (new) was from the sea level measurements made for this report and not from the original measurements. Many zero velocity photographs were taken and they all told the same story so only these three have been reproduced here.

The photographs were taken when the air velocity in the wind tunnel had been switched off so that the dipoles were falling in still air. It was as if the wind tunnel was not present, so the flight angles seen are

Figure 5

DIPOLE ANGLE DISTRIBUTIONS

DIPOLE LENGTH 28 mm

10 km Altitude and Minus 20°C

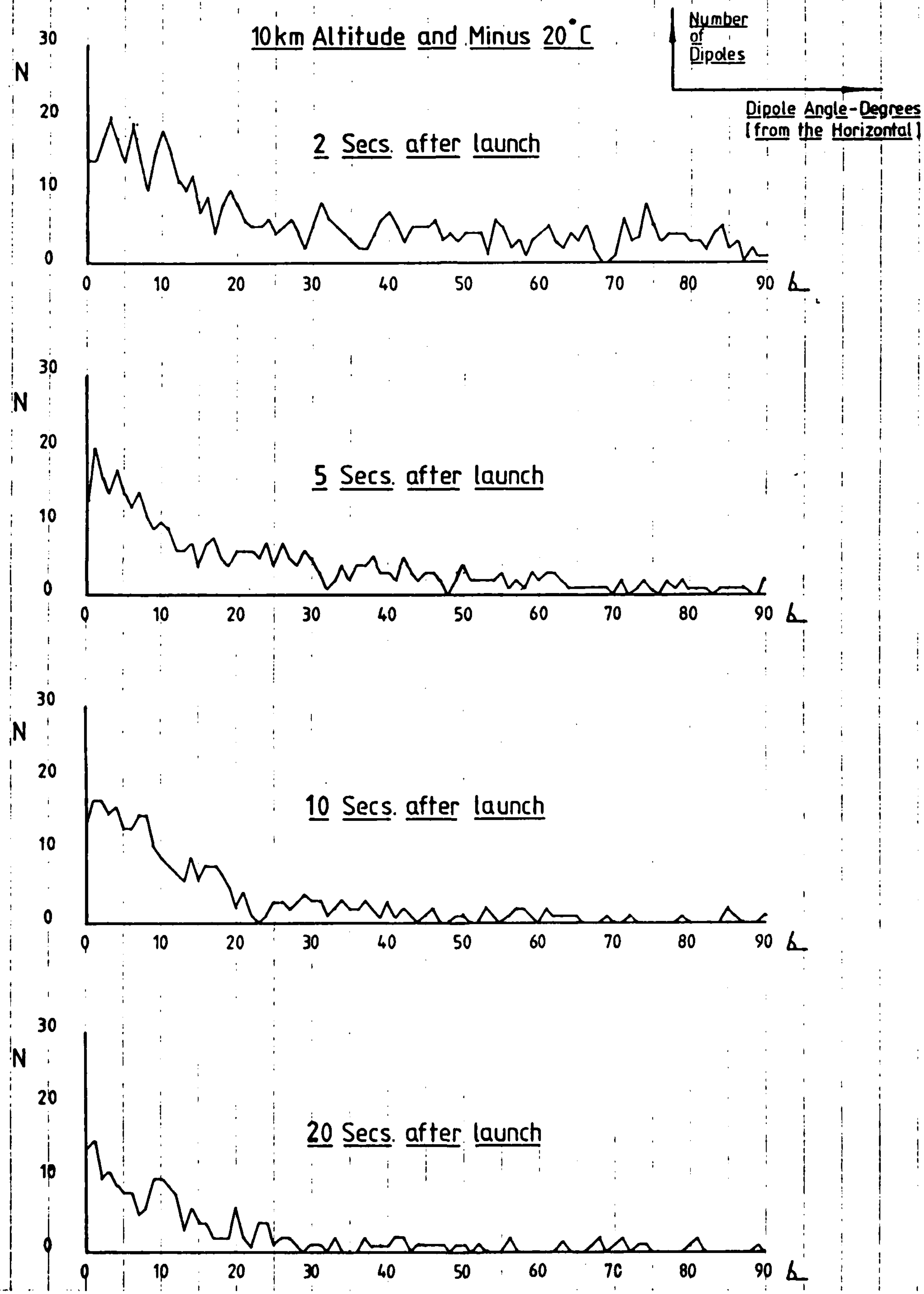
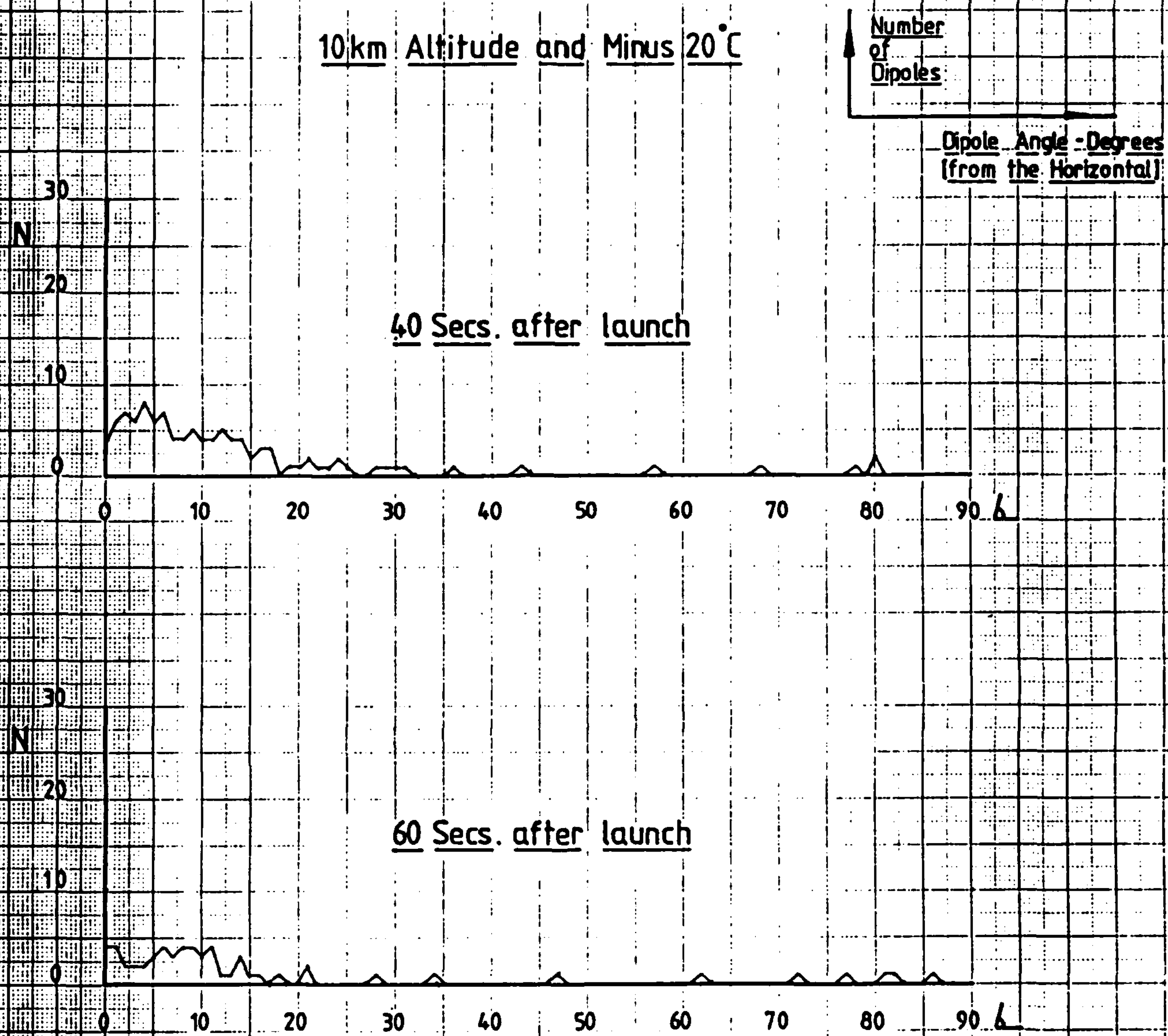


Figure 5

DIPOLE ANGLE DISTRIBUTIONS

DIPOLE LENGTH 28 mm

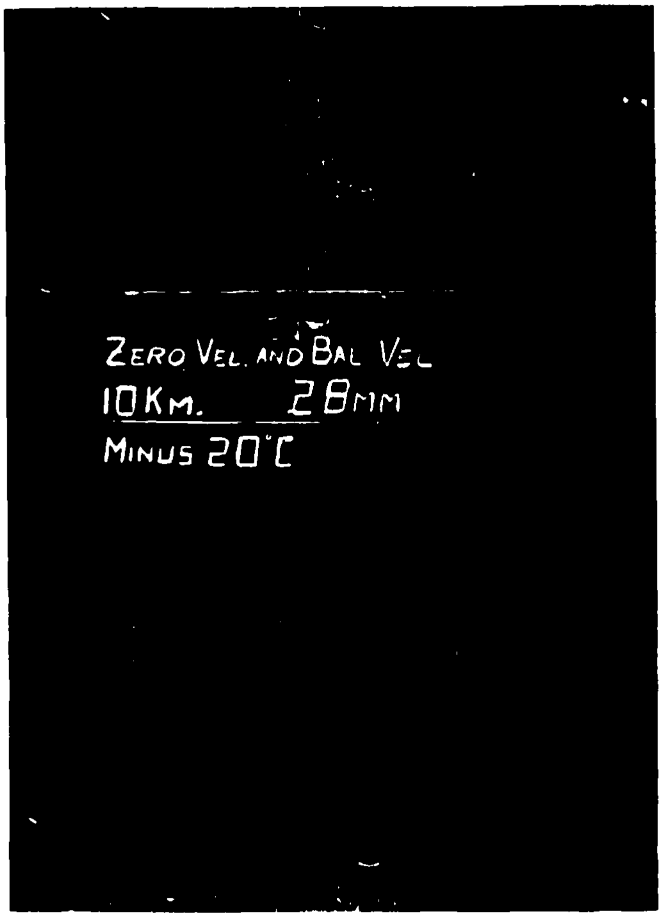
10 km Altitude and Minus 20°C



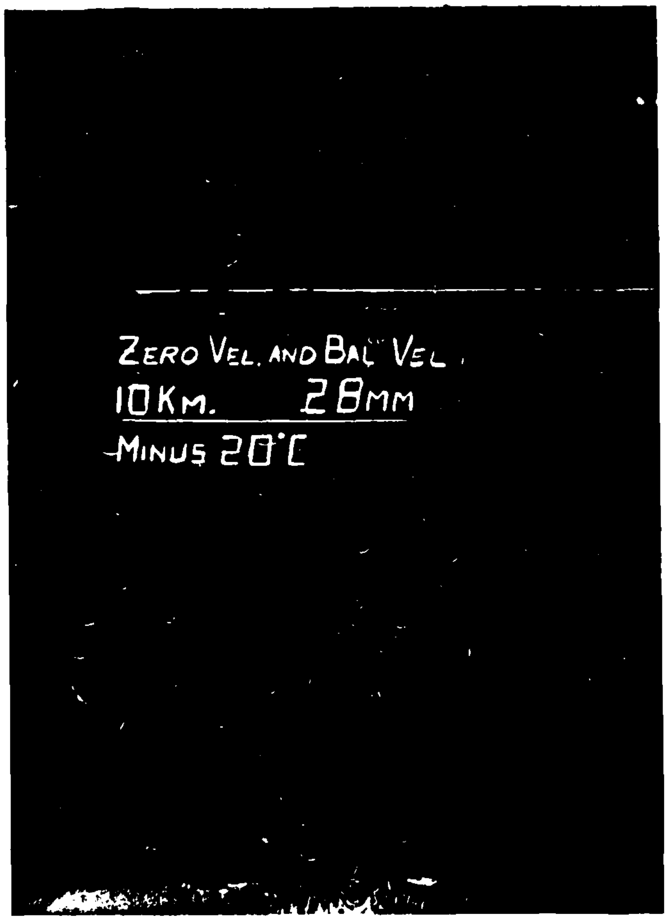
CLOUD GROWTH IN THE WIND TUNNEL

10 km Altitude and Minus 20°C

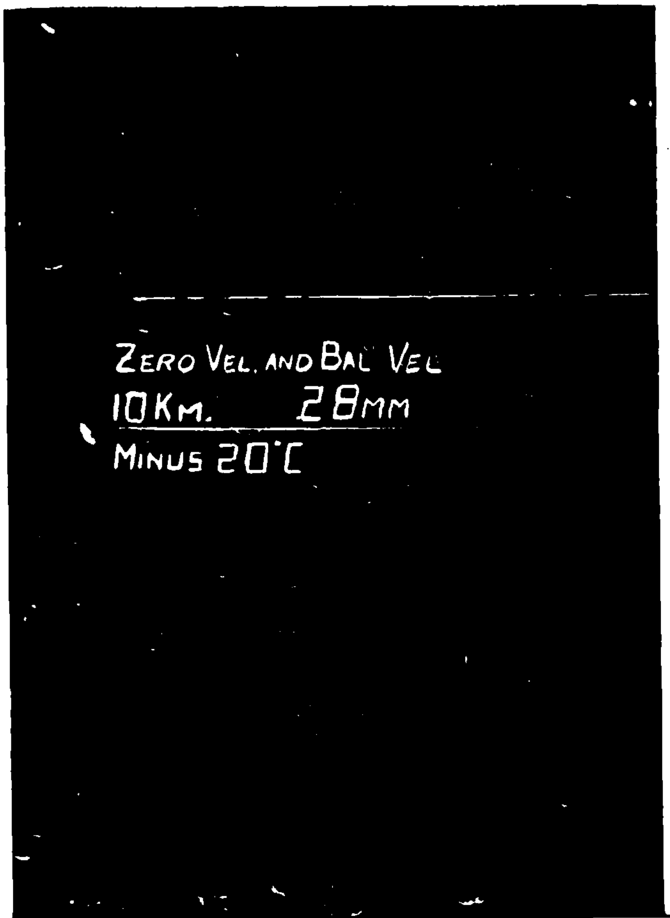
Figure 6

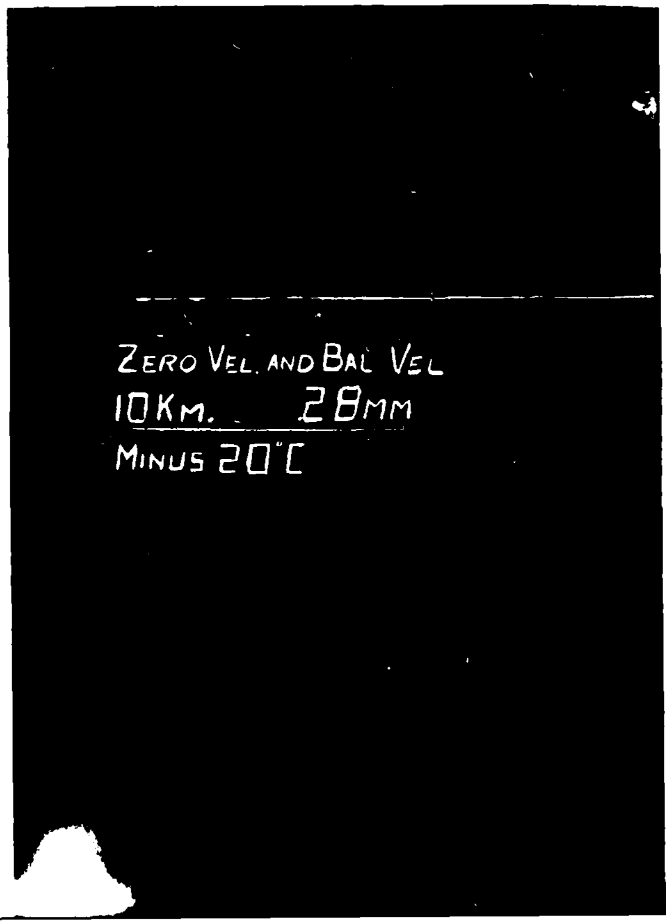


2 secs.



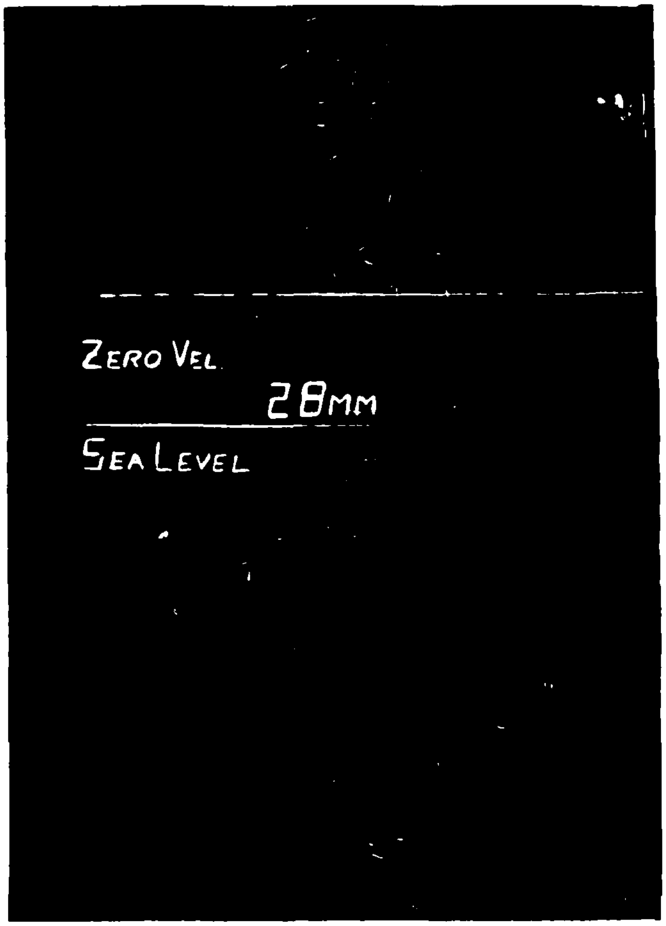
5 secs.



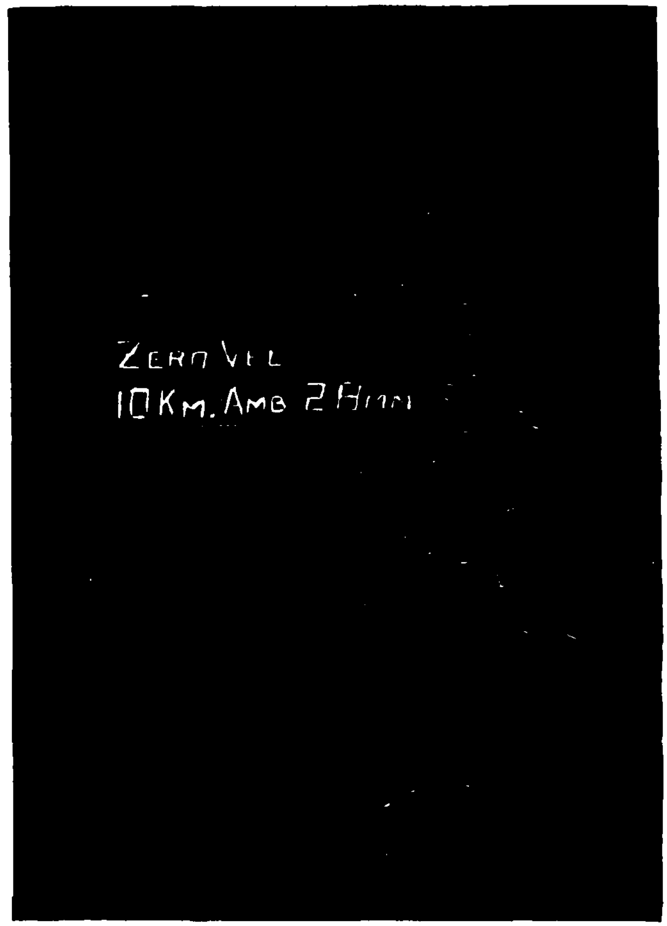


DIPOLE ORIENTATION
[air velocity = zero]

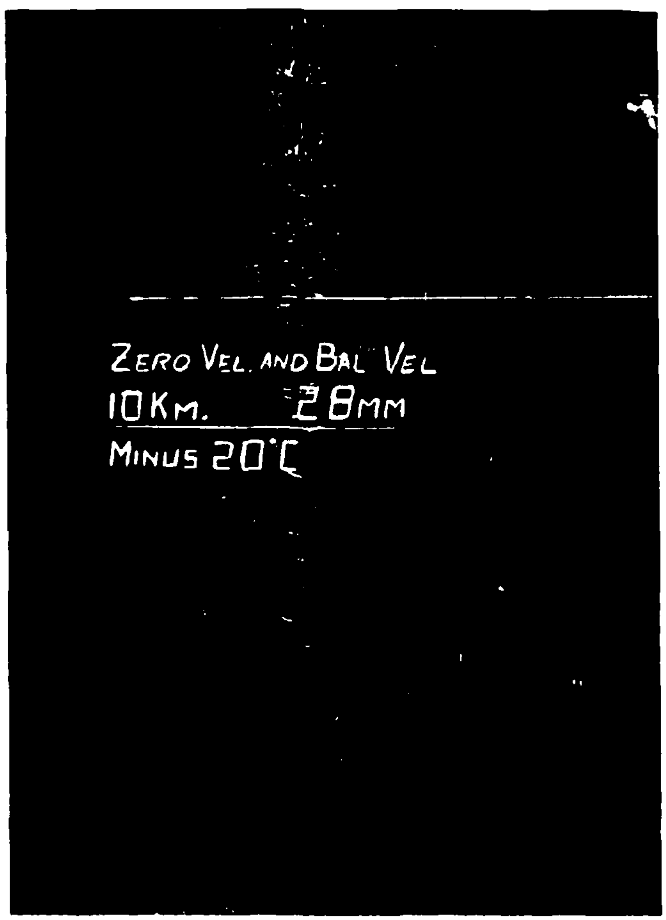
Figure 7



SEA LEVEL [NEW]



10km, PLUS 20°C



10km, MINUS 20°C

independant of any effects that the wind tunnel might have had when it was producing the balancing airstream.

The photographs show that the dipoles near the dispenser at the top of the photographs have high angles to the horizontal whereas those near the bottom fly virtually horizontally. This corresponds with previous experience in the original sea level measurements where typically dipoles stabilised into a horizontal orientation very close to the dispensing point.

The three photographs of Figure 7 reinforce the results presented in the angle distribution graphs and illustrate that the stabilisation of the dipoles into a horizontal orientation appears to be independant of both altitude and temperature.

CONCLUSIONS

The method employed was to dispense chaff dipoles in an air streamn flowing vertically upwards produced by a vertical wind tunnel, photograph the dipoles with a cine camera and later analyse the film to obtain the flight angle of the dipoles. This method also gave the distribution of the flight angle and the time dependance of that angle distribution.

The wind tunnel method examines what is happening in a fixed volume of space (which is perhaps equivalent to a fixed volume of a larger chaff cloud). The dipole cloud grows rapidly in volume from the moment that it is formed, and for the first 10 seconds or so it occupies a physically smaller volume of space than the volume examined. Beyond about 10 seconds the cloud volume is greater than the field of view and the results after that time should be viewed with that point in mind. A radar which looks at a chaff cloud does the same thing of course since the cloud is initially smaller than the resolution cell of the radar, but sooner or later the cloud grows beyond the volume of the resolution cell.

While no method of examining dipole flight is perfect, the fact that the general shape of the angle distribution does not change significantly with time, even though the dipole number, or amplitude of the graph, changes markedly, indicates that the method possesses validity beyond 10 seconds.

The overall conclusion from this series of measurements is that dipoles fly at angles very similar to those at sea level. The results obtained from all of the different conditions are remarkably similar. All show a strongly horizontal orientation for dipole flight. From a practical point of view there is no sign of vertical flight or even anything significant above 45 degrees.

Only the flight angle has been referred to in this report and it would not be correct to assume that there were no differences in other flight characteristics at high altitude. While viewing clouds of dipoles through the inspection ports in the altitude chamber there appeared to be some differences in the transient motions of the dipoles at high

altitude. These differences affect the way in which the dipoles in the clouds interact with each other and influence the rate at which the cloud grows. It was not possible to spend time examining these aspects during this work. Much more visual examination of the clouds would be needed to clarify just what the differences are.

The measurements of flight angle at altitude and minus 40 degrees Centigrade was not successful because of equipment freezing problems. Further modifications to the system would be needed to make those measurements but the results obtained so far do not jusify such work.

Acknowledgement :

The help and assistance of the Institute of Aviation Medecine, Farnborough, England for the use of the high altitude chamber in the work reported here is gratefully acknowledged. Particular thanks are due to Dr J R Allan and Mr G Richardson of the Institute.

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